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Influence on Vertical Shading Device Orientation and Thickness on the Natural Ventilation and Acoustical Performance of a Double Skin Facade

Jeehwan Lee[a*] and Jae D. Chang[a]

[a]*School of Architecture, Design & Planning, The University of Kansas, U.S.A.*

Abstract

A research showed that shading devices integrated within double skin facades (DSFs) could not only decrease direct solar heat gain but also screen unwanted sound transmission. Many researches also indicated that shading device configuration affected airflow patterns, the air velocity, and the air temperature in a DSF air cavity. At acoustical standpoints, other researches described that shading devices acted as sound barriers, however, the area of a DSF's vent opening could led to an increase in noise transmission. Therefore, the proper controls of shading devices inside a DSF air cavity can contribute to thermal and acoustical comfort with avoiding overheating and noise transmission. This study aimed at evaluating the correlation between natural ventilation potential and noise transmission loss based on the degree of orientation and thickness of vertical shading devices inside a DSF air cavity. The initial findings indicated that vertical shading devices should be controlled appropriately for balancing the requirements of thermal performance, natural ventilation efficiency and noise transmission loss.

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Keywords: Double skin facade, Natural Ventilation, Noise transmission, Vertical Shading device ;

1. Introduction

As part of preliminary study of the future research, the simulation study was performed to investigate the correlation between natural ventilation efficiency and acoustical performance using shading devices in a DSF of which construction was recently completed on campus of the University of Kansas.

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1.1. Building energy consumption

The rapid increase of urban population has resulted in not only an increase of building energy consumption due to greater reliance on Heating, Ventilation and Air Conditioning (HVAC) systems [4] but also acoustical discomfort caused by urban traffic noise. The International Energy Agency (IEA) stated that building sectors in most IEA countries consumed approximately 40% of the global energy and HVAC systems accounted for about 60% of the total energy use in buildings [5-7]. The World Health Organization (WHO) stated that urban traffic noise could cause numerous health problems such as sleep disturbance, high blood pressure, and psycho-physiological symptoms [8]. Therefore, this study investigated to see the requirements of natural ventilation efficiency and acoustical comfort through variables such as the air temperature, the air velocity, airflow patterns and noise transmission loss through vertical shading devices inside a DSF air cavity.

1.2. Shading devices

As one of the high performance building facades, DSFs have a number of advantages with the use of air cavities and shading devices which work as thermal insulation and acoustical barriers [11]. Gratia and Herde introduced how parameters such as the blind position, the blind size and DSF's vent opening affected building energy performance, and they found the cooling energy saving by about 23.2% during a sunny summer day [9]. Lee et al. (2002) investigated the relationships between the configuration of shading devices and ventilation efficiency, and they suggested that shading devices should be situated at the minimum distance of 15-centimeter between shading devices and the exterior glazing for proper ventilation efficiency [10]. Safer et al. (2005) found that the divided space of a DSF cavity by horizontal blinds was related to the air velocity, and they suggested that horizontal blinds should be positioned closely to the interior glazing to minimize overheating through a higher air velocity [12].

De Salis et al. (2002) reviewed various noise control techniques in naturally ventilated buildings, and they introduced louvers as noise barriers by screening the direct sound path using angled blades for ventilation openings [13]. Oesterle and Lutz (2001) introduced the effectiveness of a DSF's cavity as sound insulation, and they showed that the degree of sound insulation of DSFs is dependent on the size and positions of the vent openings on the exterior glazing [14]. Joynt stated that the solid looking and opaque barriers were more effective than the transparent materials in perceiving attenuated noise at a constant noise level [15]. In this study, it will concentrate on the effectiveness of the solid shading devices as acoustical barriers against outdoor noise transmission with considering natural ventilation potential.

2. Methodology

As a preliminary simulation study based on the orientation and thickness of vertical shading device before conducting the field measurements of a DSF that can potentially provide further evidence, it investigates how a DSF can balance the thermal and acoustical comfort under urban environments. The modeled DSF is a 1 story tall corridor type DSF with vertical shading devices and a DSF air cavity is designed with 16-meter in length, 8-meter in width, and 4-meter in height.

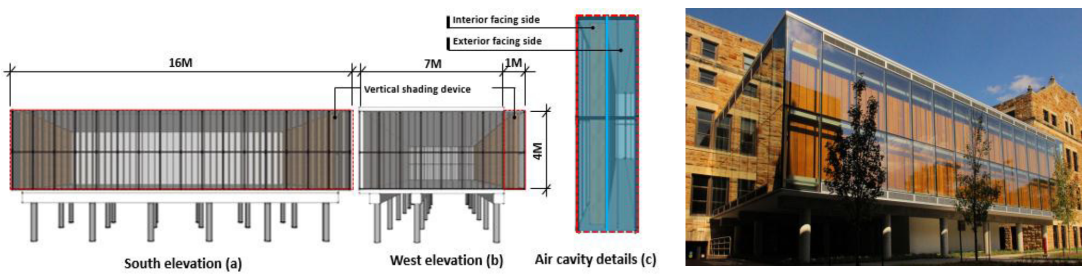

Fig. 1. (1a)South elevation; (1b) west elevation (1c) section details and perspective.

The CFD software FloVENT and AFMG SoundFlow software as in Table 1 were used to simulate airflow in a DSF air cavity and sound transmission by multi-layer structures. These programs were aimed at obtaining the numerical data for the air temperature, the air velocity, and sound transmission loss in the DSF air cavity.

Table 1. CFD and acoustical performance simulation model boundary conditions.

Classification	Parameters(unit)	FloVENT(material)	SoundFlow(material)
Ambient outdoor conditions	Temperature (°C)[1]	26	26
	Relative humidity (%)	50	50
Materials and dimensions	Exterior/Interior lazing thickness (mm)	10/10 (glass)	10/10 (glass)
	Cavity width (mm)	1000 (air)	1000 (air)
	Width of shading device (mm)	300 (wood)	300 (wood)

[1)] Average ambient air temperature in June for Lawrence, KS

To examine the air temperature, the air velocity, and sound transmission loss on the orientation and thickness of vertical shading device, seven cases of vertical shading devices were designed as in Table 2.

Table 2. Simulation scenarios of vertical shading devices.

Classification	Case 1	Case 2	Case 3	Case 4	Case5	Case 6	Case 7
Orientation	0 degree	15 degree	30 degree	45 degree	60 degree	75 degree	90 degree
Thickness	0	5 mm	10 mm	15 mm	20 mm	30 mm	40 mm

3. Results and discussion

3.1. CFD data and analysis

Figure 2 shows the CFD findings for the air temperature in the interior and exterior facing side's air cavity of vertical shading devices. It was shown that the air temperature in the interior and exterior facing side's air cavity at 90-degree angle was less than that of 0-degree angle at designated monitoring points, V1 (+0.5m), V2 (+2.0m) and V3 (+3.5m). And regarding the difference of air temperature along with the degree of orientation, it was discovered that cases in exterior facing side's air cavity of vertical shading devices were greater than cases in the interior side's air cavity.

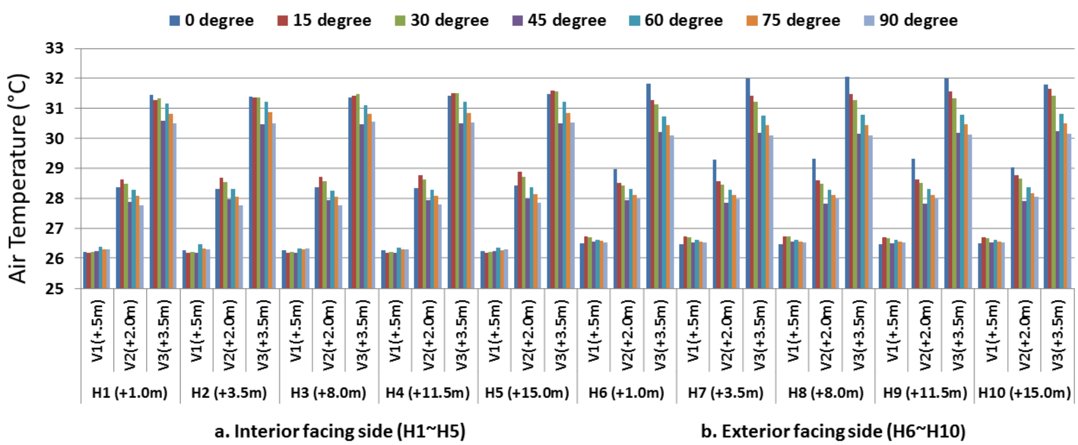

Fig. 2. (2a) Air temperature of interior facing and (2b) exterior facing side of vertical shading devices.

Figure 3 shows the CFD findings for the vertical air velocity in the interior and exterior facing side's air cavity of vertical shading devices. It was shown that the air velocity in the exterior facing side's air cavity of vertical shading devices was greater than that in the interior facing side.

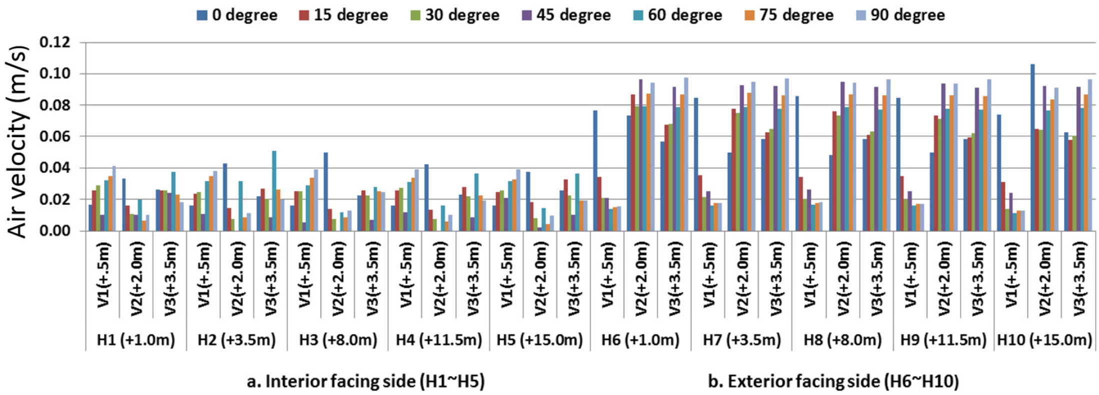

Fig. 3. (3a) Vertical air velocity temperature of interior facing and (3b) exterior facing side of vertical shading devices.

Figure 4 shows the CFD findings for the air velocity in horizontal section and airflow patterns in vertical section. When vertical shading devices were oriented 0-degree angle as in Case 1, a higher air speed was distributed across a DSF air cavity and the vertical convective currents were created. On the other hand, in case of 90-degree angle oriented as in Case 7, a higher air velocity was created near the interior and exterior glazing except for around vertical shading devices and it was observed eddy currents inside a DSF cavity.

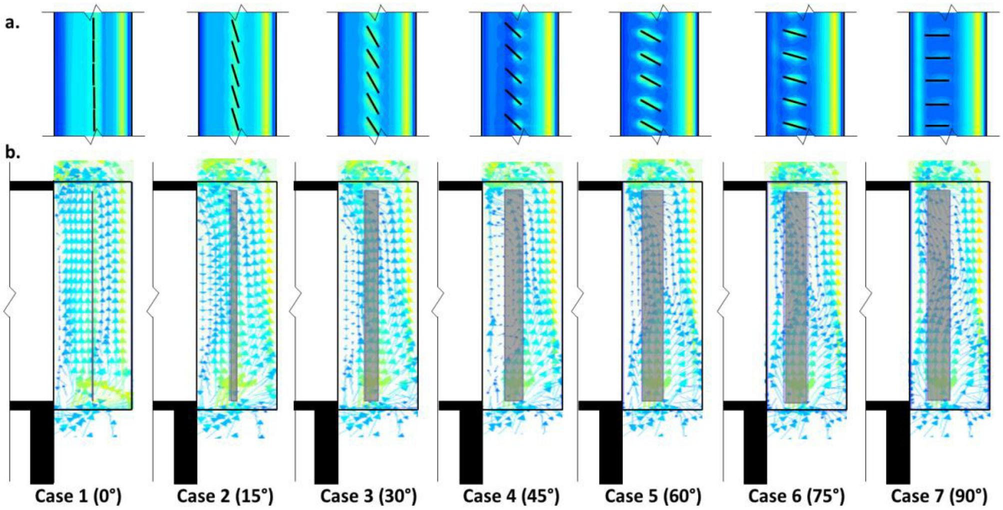

Fig. 4. (4a) Air velocity in horizontal section and (4b) airflow patterns in vertical section of horizontal shading devices.

Figure 5 shows the CFD findings for the air temperature in horizontal section and in vertical section. When vertical shading devices at 0-degree angle as in Case 1, air temperature on the interior glazing was less than that on the exterior glazing due to the solar irradiance screening-effect by shading devices. On the other hand, in case of 90-degree angle as in Case 7, the air temperature on the interior glazing also increased along with an increase of the solar irradiance transmission.

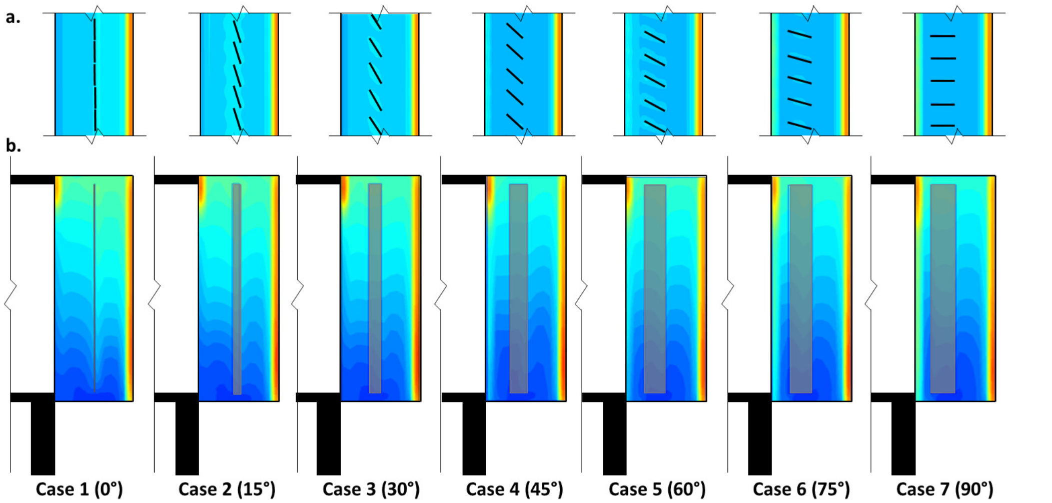

Fig. 5. (5a) Air velocity in horizontal section and (5b) airflow patterns in vertical section.

3.2. Acoustical data and analysis

Figure 6 shows sound transmission loss along with an increase of the thickness of vertical shading devices at 0-degree angle. When the shading device was not applied to a DSF cavity as in Case 1, the sound transmission loss at high frequencies was the lowest. It indicates that urban traffic noise transmitted via vent openings of DSFs can allow acoustical discomfort to the building occupants. In contrast, it was detected that an increment of thickness of vertical shading devices was effective in improving sound transmission loss. To be specific, it was observed that vertical shading devices with 30mm thick and paralleled to the external façade worked as the efficient acoustical barriers at high frequencies

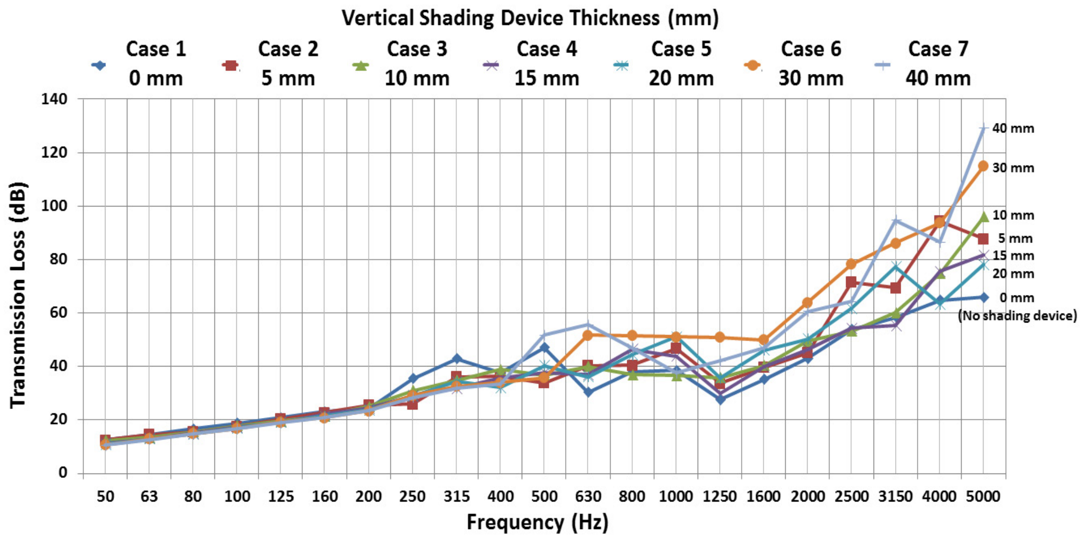

Fig. 6. Sound transmission loss based on the thickness of vertical shading devices at 0-degree angle.

4. Conclusion

This study found that the air temperature and airflow patterns were strongly dependent on the orientation of vertical shading devices. In case of vertical shading devices at 0-degree angle as in Case 1, the air temperature, the air velocity and airflow patterns were improved compared to the case of 90-degree angle orientation .To be specific, it was discovered that vertical shading devices at 0-degree angle acted as thermal barriers and created the vertical convective currents for heat dissipation. Whereas, due to the increased air temperature inside the DSF cavity by the solar irradiance transmitted via the exterior glazing as in Case 7, it needs careful considerations in designing vertical shading devices to control thermal performance in a highly glazed building facade.

Sound transmission loss was also reliant on the thickness of vertical shading devices at 0-degree angle. An increase in thickness of vertical shading devices which oriented 0-degree angle showed the improved sound transmission loss. In the future research, it is planned to investigate the relationships between sound transmission loss and their materiality along with the orientation of shading devices.

The simulation results imply that vertical shading devices at 0-degree angle is effective in ventilation efficiency and noise transmission loss as thermal and acoustical barriers. But it also needs to consider daylight harvesting based on the orientation of shading devices because there are conflicting sides among thermal/acoustical comfort and daylight availability. Therefore, this preliminary simulation study suggests that vertical shading devices oriented ranging between 0- and 30-degree angle would be appropriate for balancing the need for thermal performance, ventilation efficiency, sound transmission loss and daylight harvesting.

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